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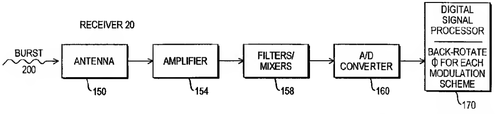

(57) Abstract: A burst of data modulated according to one modulation scheme is transmitted from the transmitter as a radio signal. Each burst contains a predefined training sequence, which may differ from burst to burst, but is known by the receiver. The receiver back-rotates the portion of the received signal corresponding to the training sequence by all available modulation schemes. Using mathematical modeling, the magnitude of the errors calculated according to each modulation scheme are compared and the modulation scheme selected is the scheme which yields the smallest error. The data in the burst may then be demodulated and processed according to the selected modulated scheme. This method has particular applicability to a GSM system in which both GMSK and EDGE modulation schemes are used but is also applicable to modulation schemes generally where the signals are modulated hy a rotation.

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Method for Blind Modulation Detection

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the demodulation of a burst of continuously rotated symbols in a mobile communication system.

2. Description of the Related Art

The standards for the GSM (Global System for Mobile Communications) mobile communications system have been evolving rapidly. In its most recent revision of the GSM standard (GSM 05.05, *Digital Cellular Telecommunications System (Phase 2+); Radio Transmission and Reception)*, the European Telecommunication Standard Institute (ETSI) has adopted standards for the use of a new radio interface technology known as EDGE (Enhanced Data Rates for GSM Evolution) which extends the GSM system currently used for speech transmission to boost network capacity and additionally provide data services and higher rates of data transmission for both circuit and packet switching via GSM phones and base stations.

Among other enhancements, EDGE offers enhanced modulation in GSM networks, which is referred to below as "EDGE Modulation". EDGE modulation is essentially a version of 8-PSK (phase shift keying) modulation in which the symbols are rotated. The EDGE modulation scheme is designed to be implemented on existing GSM systems, which currently use GMSK (Gaussian Minimum Shift Keying) modulation, without requiring any new network elements. While some cell phone sites will be upgraded to EDGE, other sites will continue, for the time being at least, to adhere to the GMSK standard.

The GMSK and 8PSK modulation schemes are described in GSM 05.04, *Digital Cellular Telecommunications System (Phase 2+); Modulation* (GSM 05.04 Version 8.0.0 Release 1999).

In a GSM system, data is transferred between a transmitter and receiver as a radio signal over a physical channel which uses both frequency and time division multiplexing to create a sequence of radio frequency channels and time slots. In accordance with the GSM standards (the latest of which was published by the ETSI as GSM Version 8.1.0 in November 1999), referring to FIG. 1, the data to be transferred, whether modulated by EDGE or GMSK, is first formed at step 100 into a burst containing a sequence of 156.25 complex symbols (each symbol having a real and imaginary part). 156.25 symbols is the number of symbols that, by definition, fit into a single timeslot for transmission by transmitter 10. A normal burst 200 shown in FIG. 3 is comprised of six components: a first "tail bits" field 210 comprising three symbols, a first set of 58 symbols of encrypted data 212, a training sequence 214 of 26 symbols in length and known as a mid-amble because it comes between two data fields, a second set of 58 symbols of encrypted data 216, a second "tail bits" field 218 comprising three symbols, and a guard period 220 which is empty and extends for a period equivalent to 8.25 symbols. In the GMSK modulation scheme, a symbol is equivalent to a bit so there are 148 bits in a burst. In the EDGE/8PSK modulation scheme, a symbol corresponds to three bits so there are 444 bits in a burst. *See* GSM 05.02 § 5.2 *Bursts (Digital Cellular Telecommunications System (Phase 2+); Multiplexing and*

Multiple Access on the Radio Path; Version 8.1.0 Release 1999).

Some bursts, other than normal bursts, do not have training sequences but the GSM standard specifies that bursts, other than normal bursts, be transmitted with GMSK modulation. Thus, for these other bursts, there is no need to differentiate between modulation schemes.

Training sequence 214 helps to demodulate the data in data field 212, 216 by helping the receiver estimate the distortion of the signal due to channel propagation. Training sequence 214 is known to the receiver before the burst 200 is received at receiver 20 but the contents of the first and second sets of data 212, 216 are not known.

To improve the dynamic characteristics of the transmitted signal (step 110), each symbol in the entire sequence of complex symbols is rotated by an additional amount ϕ beyond the rotation of the previous symbol, the amount of the rotation depending on the modulation scheme. As described further below, in EDGE, the rotation is explicitly performed according to equation (1) given below. In GMSK, bits are first differentially encoded and then modulated, yielding what is "effectively" a rotation which conforms to equation (1). This radio signal is then transmitted as a burst over an unknown linear channel, at step 120, and, after being affected by various sources of noise, the burst is received at receiver 20 (step 140).

While permitting the choice of either modulation scheme, ETSI will not be requiring the insertion of any explicit information, such as flags or

pilot data, to tell receiver 20 how the data has been modulated so that receiver 20 may properly demodulate the data. Because no modulation scheme is explicitly indicated and since some transmitters in the upgraded GSM system will be broadcasting in GMSK and others will be broadcasting in EDGE, or even a single transmitter may switch between GSK modulation and EDGE modulation, there is a need for a method for quickly and reliably detecting, on a burst-to-burst basis, which modulation scheme was used to modulate the data in a received radio signal so that the receiver can accurately demodulate and process the data. An especially useful blind modulation detection method would be broadly applicable to distinguishing between modulation methodologies other than GMSK and EDGE. There is currently no such blind detection method.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method for detecting at a receiver in a mobile communications system the modulation scheme used in a modulated burst received from a system transmitter.

It is a further object of this invention to provide a method for blind modulation detection for a GSM mobile communications system using more than one modulation scheme.

It is a further object of this invention to provide a method for blind modulation detection which provides both a channel estimate and a noise-variance estimate.

It is a further object of this invention to provide a method for blind modulation detection which

can be applied more generally to more than two particular modulation schemes.

In accordance with the present invention, a signal is transmitted over a digital radio communication link from a transmitter to a receiver. The communication link is preferably a link in a GSM mobile communications system, which transmits a radio signal as a burst of symbols containing sequences of data and a training sequence. Before being transmitted, the symbols are rotated according to one of various modulation schemes available in the system, each modulation scheme rotating the symbols by a different angle of rotation. No information is included in the burst which will explicitly tell the receiver what modulation scheme was used to modulate the symbols in that burst. The burst is received at the receiver, where the portion corresponding to the training sequence is back-rotated for each available modulation scheme. For each modulation scheme, the back-rotated portion of the training signal is mathematically modeled as a convolution of the original sequence of symbols in the burst and a channel impulse response plus an error measurement, a channel impulse response is calculated for each modulation scheme, for example using least squares (which minimizes the squared model error), and the calculated channel impulse response is inserted into the mathematical model to determine the error for each modulation scheme. The magnitudes of the square of the errors for each modulation scheme are then compared and the modulation scheme with the smallest error is selected as the modulation scheme to be used by the receiver to demodulate the data in the analyzed burst.

The calculations are generally performed at a digital signal processor at the receiver.

Other objects and features of the present invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits of the invention, for which reference should be made to the appended claims. It should be further understood that the drawings are not necessarily drawn to scale and that, unless otherwise indicated, they are merely intended to conceptually illustrate the structures and procedures described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings wherein like reference numerals denote similar elements throughout the several views:

FIG. 1 is a block diagram of the signal flow concept in accordance with a preferred embodiment of the present invention;

FIG. 2 is a block diagram of the receiver structure;

FIG. 3 is a diagrammatic view of a burst of symbols in a GSM system;

FIG. 4(a) is a graphical representation of the "effective" rotation of four bits of a training sequence by differential encoding and GMSK modulation scheme to form a radio signal or a portion thereof;

FIG. 4(b) is a graphical representation of the back-rotation of the radio signal or portion thereof that is representative of the sequence of bits "effectively" rotated in FIG. 4(a);

FIG. 4(c) is a graphical representation of the rotation of four bits of a training sequence using the EDGE modulation scheme to form a radio signal or a portion thereof; and

FIG. 4(d) is a graphical representation of the back-rotation of the radio signal or portion thereof that is representative of the sequence of bits "effectively" rotated in FIG. 4(c).

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

GMSK modulation and EDGE modulation share two significant properties. First, in both modulation schemes, a part of the burst (transmitted sequence) is a training sequence known to the receiver. The training sequence may change from one burst to another, but the receiver knows what training sequence is used for a particular burst. Referring to FIG. 3, in both GMSK and EDGE, the training sequence 214 is the 26 symbol mid-amble which is both preceded and followed by a sequence of data 212, 216. A second significant property which GMSK modulation and EDGE modulation share is that each modulation scheme rotates the symbols, whether by explicit rotation as in EDGE or only "effectively" as in GMSK.

In GMSK, each bit having a value of 0 or 1 is first differentially-encoded, resulting in the creation of a new sequence of bits having a value of either -1 or 1, where the k^{th} bit is 1 if the k^{th} and the $(k-1)^{th}$ bits in the original sequence are the same, and the k^{th} bit is -1 if the k^{th} and the $(k-1)^{th}$ bits are different. (The values of 1 and -1 selected for differential encoding in current GSM systems are not crucial for the present invention and other values may alternatively be used).

The resulting sequence of encoded bits are then phase-modulated by GMSK modulation before being sent to the transmitter. The combination of encoding and GMSK modulation allows a receiver to interpret the received sequence of symbols as if each symbol in the burst is rotated by an additional $\pi/2$ radians over the effective rotation of a previous symbol. This allows a rotation in the transmitter signal to be modeled as if the rotation was introduced by the transmitter 10. In EDGE, each symbol is explicitly rotated by the transmitter 10 by an additional $3\pi/8$ radians over the rotation of a previous symbol in the burst. Thus, conceptually there is no difference between the two modulation schemes.

A graphical illustration of the GMSK and EDGE modulation schemes is shown in FIGS. 4(a)-4(d). Referring to FIG. 4(a), in one example, a training sequence of four bits 1101 is to be transmitted (line 301). Differential encoding generates a new sequence of 1 and -1 (line 302). These encoded values determine how much the phase of final waveform changes: a -1 in the sequence changes the phase of the transmitted signal by $-\pi/2$ and a 1 changes the phase by $\pi/2$ (line 303). This is shown graphically at line 304 where, moving from the leftmost graph to the rightmost, the first encoded bit 1 changes the phase of the signal by $\pi/2$, the second encoded bit 1 changes the phase an additional $\pi/2$, the third encoded bit -1 changes the phase by $-\pi/2$ over the previous phase, and the fourth encoded bit -1 changes the phase again by $-\pi/2$.

FIG. 4(b) describes the GMSK receiver operations. Receiver 20 back-rotates the sequence of symbols by $-\pi/2$ for each symbol (line 305). The

reconstructed training sequence of 1101 is determined by associating with a zero phase the bit 1 and associating with a π radians phase the bit 0, as is shown graphically at 306.

FIG. 4(c) describes the EDGE transmitter operations. The phase of the four training symbols to be transmitted is 0, 0, π, and 0 (line 307). The transmitter explicitly rotates these symbols with $3\pi/8$ radians per symbol (line 308), as is shown graphically at 309.

FIG. 4(d) describes the EDGE receiver operations. Receiver 20 back-rotates the sequence of symbols with $-3\pi/8$ for each symbol (line 310) and the phase of the resulting symbols reconstructs the phase of the original sequence of symbols, as shown graphically at 311.

The invention utilizes mathematical modeling to take advantage of these shared properties and shared differences to determine which modulation scheme has been used. In fact, this invention is more broadly applicable to the modulation schemes which share these two properties. The modeling is only performed on the known training symbols, which are the only significant symbols for this purpose. Matrix and vector notation is used below to more simply describe the various steps in the process.

Assuming the training sequence is generalized to consist of N complex symbols (and is not limited to a 26 symbol mid-amble), these N symbols are collected in an $N \times 1$ vector x. In the GSM system, the N training symbols take only two possible values, -1 and 1 but the values of this training symbols are not crucial to the

invention. Transmitter 10 creates complex data symbols $\tilde{x}_k$ for each of the symbols in the burst by rotating each symbol by ϕ radians more than the rotation of the previous symbol. Thus, the N symbols are rotated at step 110 according to the following equation:

$$\tilde{x}_k = x_k e^{j2\pi\phi k} \qquad k=0,\ 1,\ 2,\ \ldots,\ N \qquad (1)$$

wherein the resulting vector $\tilde{x}$ is an $N \times 1$ vector containing the symbols $\tilde{x}_k$ where k = 0 to N. For EDGE modulation $\phi=\phi_0=3\pi/8$ radians and for GMSK modulation $\phi=\phi_1=\pi/2$ radians. This relationship can be more easily expressed using matrices as

$$\tilde{x}_k = R_i\, x_k \qquad (2)$$

where $R_i = \begin{bmatrix} e^{j\phi_i 0} & 0 & \cdots & 0 \\ 0 & e^{j\phi_i 1} & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & e^{j\phi_i [N-1]} \end{bmatrix}$ (i = 0 for EDGE, i = 1 for GMSK) (3)

The modulated symbols are transmitted at step 120 over a radio channel as a burst which is exposed to the distortions of noise, including the impairments caused by fading, multipath propagation, channel dispersion, additive noise, etc., at step 130, before being received by receiver 20 at step 140.

FIG. 2 illustrates a representative structure of receiver 20 for practicing blind modulation detection. The burst 200 is received by antenna 150, where the signal amplified by amplifier 154, and passes through filters and mixers 158. The signal is then converted from an analog to digital by A/D converter 160.

Because it does not know the modulation scheme used at transmitter 10, receiver 20 demodulates the burst using both demodulation schemes, GMSK and EDGE, at digital signal processor 150, to generate the two possible solutions. Digital signal processor 150 may be any digital signal processor sufficiently powerful to perform the necessary calculations. To demodulate the burst, the rotation applied by GMSK and EDGE is reversed ("back-rotated"). For each of symbols N, y_i is calculated. y_o is calculated for a back-rotation for an EDGE-modulated signal and y_1 is calculated for a back-rotation for a GMSK-modulated signal. The generalized equation for back-rotation is:

$$y_i = R_i^{-1} y \quad (i = 0 \text{ for EDGE, } i = 1 \text{ for GMSK}) \qquad (4)$$

wherein each y_i is an $N \times 1$ vector.

y_o and y_1 are now modeled as a convolution of the transmitted signal X and a channel impulse response vector h_i for a linear channel. (Each element in vector h_i is represented as $h(n)$.) The channel impulse response, which takes into account channel dispersion, has p taps $h(0) \ldots h(p-1)$, which are complex values, each tap representing a gain and a phase. The value of p depends on the physical characteristics of the radio channel, especially upon the interference with the propagation of the radio waves by the environment, including dispersion, reflection, etc. by, for example, physical objects. In an urban environment, for example, the value of p is usually selected as a relatively small value because the variations in the arrival times of the various reflections of the radio waves are small. In hilly terrain, on the other hand, reflections of the radio waves may come from objects far away from the

receiving antenna so the selected value of p should be relatively larger.

The channel is fed with an input signal $x(k)$ (the transmitted signal) and generates a distorted output signal $y(k)$ (the received signal). The output signal is a function of the input signal according to the following equation:

$$y(k) = \sum_{n=0}^{p-1} h(n)x(k-n) \qquad (5)$$

For instance, the output signal $y(14) = h(0)x(14) + h(1)x(13) +\ldots+ h(p-1)x(14-(p-1))$. An output signal is thus the weighted sum of the associated input signal and the last $p-1$ input signals. The model is characterized, using vector notation, by the equation:

$$y_i = Xh_i + e_i \qquad i = 0,\ 1 \qquad (6)$$

where e_i represents any error in the model.

While $x(k)$ is known for the transmitted training sequence, due to the convolution which takes into account channel distortion in the transmission of the radio signal, the first $p-1$ symbols in y_i depend on the unknown data symbols preceding the transmitted training sequence. These first $p-1$ symbols in y_i are therefore disregarded. For example, using equation (5) where $p = 5$, the output signal $y(1) = h(0)x(1) + h(1)x(0) + h(2)x(-1) + h(3)x(-2) + h(4)x(-3)$. While $x(1)$ is the first transmitted symbol, $x(0)$, $x(-1)$, $x(-2)$, and $x(-3)$ are four unknown data symbols preceding the training sequence. Therefore, the first ($p-1$ =) 4 symbols of the received training sequence cannot be predicted.

The remaining *N-p+1* received symbols are collected in a reduced-size *(N-p+1 x 1)* vector still denoted as *y*. Matrix *X* is modeled as an *(N-p+1 x p)* convolution matrix defined as

$$\mathbf{X} = \begin{pmatrix} x_p & x_{p-1} & x_{p-2} & \cdots & & x_1 \\ x_{p+1} & x_p & x_{p-1} & \cdots & & x_2 \\ x_{p+2} & x_{p+1} & x_p & \cdots & & x_3 \\ x_{p+3} & x_{p+2} & x_{p+1} & \cdots & & x_4 \\ \vdots & \vdots & \vdots & & \ddots & \vdots \\ x_N & x_{N-1} & x_{N-2} & \cdots & & x_{N-p+1} \end{pmatrix} \quad (7)$$

where *p* is the number of elements in the channel. This matrix *X* describes the assumption about how the received sequence is related to the transmitted sequence and the channel impulse response.

Two *(px1)* channel estimate vectors $\hat{h}_0$ and $\hat{h}_1$, which estimate the energy of each signal and are characterized by a gain and a phase, are then calculated. The least squares estimation method is one method for computing the solution for $\hat{h}_1$ (to generate the best fit). Using this method and setting $e_i = 0$ (to minimize the Euclidean distance between the statistics and the perfect model Xh_i), the channel estimate vector is calculated as:

$$\hat{h}_i = \left(X^H X\right)^{-1} X^H y_i \qquad i = 0, 1 \quad (8)$$

where X^H is the Hermitian transpose of *X* (the complex conjugate of X^T) and $\left(X^H X\right)^{-1} X^H$ is known as the "pseudo-inverse" of *X*. Since we assume that *y=Xh*, the least-squares estimation method can be interpreted as simply "inverting" the signal model with the pseudo-inverse.

The invention is not limited to a least squares estimation method. Alternative methods for channel estimation include the minimum-mean-squared-error estimator and channel sounding methods.

Using a first approach for determining the modulation scheme, the energy in the two vectors $\hat{h}_0$ and $\hat{h}_1$, *i.e.*, the sum of the squares of the channel taps for each of the vectors, may be compared and the modulation with the highest energy determines the modulation scheme for the receiver. Thus, the equation for determining modulation scheme is

$$\left\|\hat{h}_0\right\|^2 \underset{GMSK}{\overset{EDGE}{\gtrless}} \left\|\hat{h}_1\right\|^2 \qquad (9)$$

i.e., where the energy of the $\hat{h}_0$ vector is larger than the energy of the $\hat{h}_1$ vector, the modulation scheme is determined to be EDGE, and where the energy of the $\hat{h}_1$ vector is larger than the energy of the $\hat{h}_0$ vector, the modulation scheme is determined to be GMSK. This analysis is based on the principle that the total energy in the channel estimate is higher when the received sequence is back-rotated with the correct angle.

Using simulations, it has been determined that this approach is less accurate than a second approach. In this second approach, instead of comparing the squared magnitudes of the two vectors $\hat{h}_0$ and $\hat{h}_1$, estimates of $\hat{h}_0$ and $\hat{h}_1$ are calculated and these values are inserted back into the following equation:

$$e_i^2 = \left\| y_i - X\hat{h}_i \right\|^2 \quad (i = 0,\ 1) \quad (10)$$

This measurement can be interpreted as the remaining error after fitting the received data to linear channel model $y = Xh$. The modulation scheme is then determined by choosing the modulation corresponding to the rotation R_i that minimizes e_i^2. If a wrong back-rotation angle is used by the receiver 20, the transmitted signal and the back-rotated signal will not match, and e_i^2 will be relatively large. For the correct back-rotated sequence, however, e_i^2 is likely to be much smaller. The modulation detector is therefore

$$e_0^2 \underset{EDGE}{\overset{GMSK}{\gtrless}} e_1^2 \quad (11)$$

which is equivalent to

$$X\hat{h}_i \Big\| \quad - \quad \Big\|^2 \underset{EDGE}{\overset{GMSK}{\gtrless}} \left\| y_i - X\hat{h}_i \right\|_{y_0}^2 \quad (12)$$

Using the modulation scheme selected by the modulation detector, the data at 212, 216 in burst 200 may be demodulated as appropriate to that scheme and the data processed accordingly. By calculating and comparing e_i^2 for $i = 0,\ 1$, it has been found that the error rate for blindly detecting the modulation scheme is comparatively small.

The blind detection method provides two side benefits. As one benefit, the estimated channel impulse response is generally needed later in the receiver where

the unknown data symbols are detected and it is determined what message was transmitted by the transmitter. As a second, added benefit, by calculating e_i^2, the receiver also obtains a good estimate of the noise variance (defined as the energy of the transmitted signal divided by the average power of the additive channel noise) due to the distortion of the transmitted burst by noise (apart from a scaling). The estimated noise variance e_i^2 is used later by the receiver along with the channel impulse response to help provide a reliable reconstruction of the transmitted data symbols in the rest of the burst.

The above invention can be generalized to detect more than two modulation schemes where there is a difference in the angle of rotation between the two modulation schemes. It may also be used in a system in which the training sequence is not a mid-amble but is rather moved elsewhere within the burst, as long as the receiver knows where the training sequence is located. The modulation schemes must, however, have the two properties common to the GMSK and EDGE schemes which, again, are:

(1) At least a part of the transmitted sequence must be known at the receiver (*e.g.*, a training sequence); and

(2) The modulation schemes must differ from each other by a symbol-wise rotation with different angles.

Thus, while there have shown and described and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions and substitutions and

changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit of the invention. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of design choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

CLAIMS

What is claimed is:

1. A method for detecting a modulation scheme of a radio signal transmitted over a digital radio communication link, said modulation scheme selected from a group consisting of a plurality of modulation schemes in which a sequence of symbols having a training sequence is rotated by a different amount in each of the modulation schemes in said group and is formed into the radio signal, said method comprising:

receiving the radio signal at a receiver;

demodulating a portion of the received radio signal representing the training sequence by back-rotating the portion of the radio signal for each of the plurality of modulation schemes;

for each of the plurality of modulation schemes, modeling the sequence of symbols as a convolution of the portion of the radio signal and a channel impulse response plus an error measurement, and calculating the square of the error; and

comparing the square of the error for each of the plurality of modulation schemes to determine the selected modulation scheme to be whichever of the plurality of modulation schemes has an error whose magnitude squared is smallest.

2. The method of claim 1 wherein said group of modulation schemes comprises GMSK modulation and EDGE modulation, and said step of determining at said receiver the selected modulation scheme comprises determining whether the modulation scheme is GMSK modulation or EDGE modulation.

3. The method of claim 1 wherein said digital radio communication link comprises a link in a GSM mobile communications system.

4. The method of claim 1 wherein said receiver further comprises a digital signal processor, and said calculation of said square of the error and said comparison of the square of the error is performed by said digital signal processor.

5. The method of claim 1 further comprising informing said receiver of the training sequence in the radio signal.

6. The method of claim 1 wherein the radio signal is devoid of data explicitly indicating the selected modulation scheme.

7. The method of claim 1 wherein the radio signal has a second portion preceding the first portion and not containing training sequence data and wherein said step of modeling comprises forming a convolution matrix and ignoring in the matrix a plurality of values, obtained by the convolution formation, which are representative of both a first part of the training sequence and the second portion of the radio signal.

8. The method of claim 1 further comprising, for each of the plurality of modulation schemes, calculating the channel impulse response, and using the channel impulse response in said calculation of said error.

9. The method of claim 8 wherein said calculation of the channel impulse response comprises calculating the channel impulse response using a least squares solution.

10. The method of claim 1 further comprising, after determining the selected modulation scheme, using

the selected modulation scheme to demodulate data in the radio signal.

11. A method for detecting a modulation scheme of a radio signal transmitted over a digital radio communication link, said modulation scheme selected from a group consisting of a plurality of modulation schemes in which a sequence of symbols having a training sequence is rotated by a different amount in each of the modulation schemes in said group and is formed into the radio signal, said method comprising:

receiving the radio signal at a receiver;

demodulating a portion of the received radio signal representing the training sequence by back-rotating the portion of the radio signal for each of the plurality of modulation schemes;

for each of said plurality of modulation schemes, modeling the sequence of symbols as a convolution of the portion of the radio signal and a channel impulse response plus an error measurement, and calculating the channel impulse response; and

comparing the energy of the channel impulse response for each of the plurality of modulation schemes to determine the selected modulation scheme to be whichever of the plurality of modulation schemes has a higher total energy.

12. The method of claim 11 wherein said group of modulation schemes comprises GMSK modulation and EDGE modulation, and said step of determining at said receiver the selected modulation scheme comprises determining whether the modulation scheme is GMSK modulation or EDGE modulation.

13. The method of claim 11 wherein said digital radio communication link comprises a link in a GSM mobile communications system.

14. The method of claim 11 wherein said receiver further comprises a digital signal processor, and said calculation of said square of the error and said comparison of the square of the error is performed by said digital signal processor.

15. The method of claim 11 further comprising informing said receiver of the training sequence in the radio signal.

16. The method of claim 11 wherein the radio signal is devoid of data explicitly indicating the selected modulation scheme.

17. The method of claim 11 wherein the radio signal has a second portion preceding the first portion and not containing training sequence data and wherein said step of modeling comprises forming a convolution matrix and ignoring in the matrix a plurality of values, obtained by the convolution formation, which are representative of both a first part of the training sequence and the second portion of the radio signal.

18. The method of claim 11 further comprising, after determining the selected modulation scheme, using the selected modulation scheme to demodulate data in the radio signal.

19. The method of claim 11 wherein said calculation of the channel impulse response comprises calculating the channel impulse response using a least squares solution.

20. A receiver for receiving a radio signal transmitted over a digital radio communication link, the radio signal formed from a modulated sequence of symbols which are modulated according to a modulation scheme

selected from a group consisting of a plurality of modulation schemes in which a sequence of symbols having a training sequence is rotated by a different amount in each of said modulation schemes in said group, said receiver comprising:

means for demodulating a portion of the received radio signal representing the training sequence by back-rotating the portion of the received radio signal for each of the plurality of modulation schemes;

means for calculating a channel impulse response based on a modeling of the sequence of symbols as a convolution of the portion of the received radio signal and the channel impulse response plus an error measurement, for each of the plurality of modulation schemes, and for calculating the square of the error; and

means for comparing the square of the error for each of the plurality of modulation schemes to determine the selected modulation scheme to be whichever of the plurality of modulation schemes has an error whose magnitude squared is smallest.

21. The receiver of claim 20 wherein the digital radio communication link comprises a link in a GSM mobile communications system and the plurality of modulation schemes comprise GMSK modulation and EDGE modulation.

22. The receiver of claim 20 wherein the demodulating means, modeling means and comparing means comprise a digital signal processor.

23. The receiver of claim 20 further comprising means for calculating the channel impulse response using a least squares solution.

24. A receiver for receiving a radio signal transmitted over a digital radio communication link, the radio signal formed from a modulated sequence of symbols which are modulated according to a modulation scheme selected from a group consisting of a plurality of modulation schemes in which a sequence of symbols having a training sequence is rotated by a different amount in each of said modulation schemes in said group, said receiver comprising:

means for demodulating a portion of the received radio signal representing the training sequence by back-rotating the portion of the received radio signal for each of the plurality of modulation schemes;

means for calculating a channel impulse response based on a modeling of the sequence of symbols as a convolution of the portion of the received radio signal and the channel impulse response plus an error measurement; and

means for comparing the energy of the channel impulse response for each of the plurality of modulation schemes to determine the selected modulation scheme to be whichever of the plurality of modulation schemes has a higher total energy.

25. The receiver of claim 24 wherein said digital radio communication link comprises a link in a GSM mobile communications system and said plurality of modulation schemes comprise GMSK modulation and EDGE modulation.

26. The receiver of claim 24 wherein said demodulating means, modeling means and comparing means comprise a digital signal processor.

27. The receiver of claim 24 further comprising means for calculating the channel impulse response using a least squares solution.

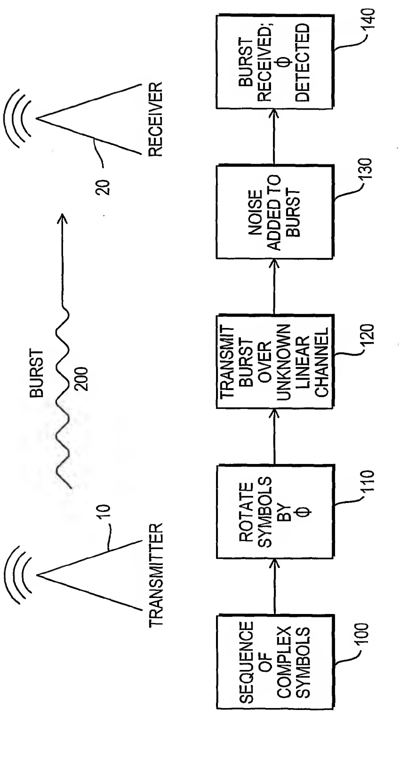

FIG. 1
PRIOR ART

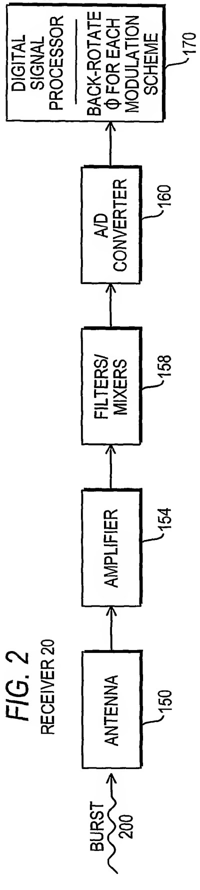

FIG. 2
RECEIVER 20

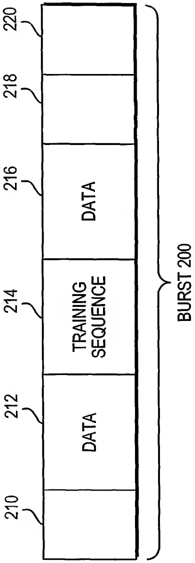
220
218
216
DATA
214
TRAINING SEQUENCE
212
DATA
210
BURST 200

FIG. 3

GMSK:

TRAINING SEQUENCE:	1	1	0	1	301
DIFFERENTIAL PRE-CODING:	1	1	-1	-1	302
PHASE SHIFT (NO SHAPING):	$\pi/2$	$\pi/2$	$-\pi/2$	$-\pi/2$	303

TRANSMITTED SYMBOLS (SCHEMATIC):

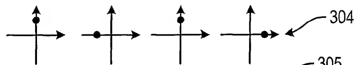

FIG. 4(a)

BACK-ROTATION ($-\pi/2$ PER SYMBOL):	$-\pi/2$	$-\pi$	$-3\pi/2$	-2π	305

AFTER BACK-ROTATION (SCHEMATIC):

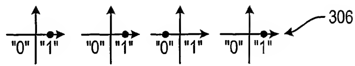

FIG. 4(b)

EDGE:

TRAINING SEQUENCE: (PHASE OF 8-PSK SYMBOLS)	0	0	π	0	307
ROTATION ($3\pi/8$ PER SYMBOL):	$0\pi/8$	$3\pi/8$	$6\pi/8$	$9\pi/8$	308

TRANSMITTED SYMBOLS (SCHEMATIC):

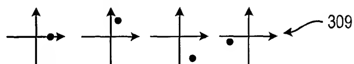

FIG. 4(c)

BACK-ROTATION ($-3\pi/8$ PER SYMBOL):	$-0\pi/8$	$-3\pi/8$	$-6\pi/8$	$-9\pi/8$	310

AFTER BACK-ROTATION (SCHEMATIC):

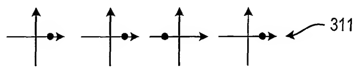

FIG. 4(d)

INTERNATIONAL SEARCH REPORT

In ional Application No
PCT/IB 00/01749

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L27/00 H04L25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99 39484 A (NOKIA TELECOMMUNICATIONS OY ; NIEMELAE KARI (FI); PIIRAINEN OLLI (FI)) 5 August 1999 (1999-08-05) page 4, line 24 -page 5, line 20	11-16, 18,24-26
Y	figures 2,4A,4B	1-10,17, 19-23,27
Y	CROZIER, S.N.; FALCONER, D.D.; MAHMOUD, S.A.: "Least sum of squared errors (LSSE) channel estimation" RADAR AND SIGNAL PROCESSING, IEE PROCEEDINGS F, vol. 138, no. 4, 1 August 1991 (1991-08-01), pages 371-378, XP002162326 New York page 372, left-hand column, line 9 -right-hand column, line 45	1-10,17, 19-23,27

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 March 2001	02/04/2001

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

In ional Application No
PCT/IB 00/01749

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9939484 A	05-08-1999	FI 980219 A	31-07-1999
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		CN 1256040 T	07-06-2000
		EP 0972384 A	19-01-2000
		NO 994743 A	29-09-1999